Extending the Mission:

NATO AEW Beyond Line-of-Sight Airborne IP Communications

Richard F. BIRD
Senior Scientist, CAT-5 Joint Intelligence, Surveillance & Reconnaissance

Don KALLGREN
Principal Scientist, CAT-9 Communications Infrastructure Services
NATO Consultation, Command and Control Agency
PO Box 174, 2501CD The Hague, The Netherlands

richard.bird@nc3a.nato.int / don.kallgren@nc3a.nato.int

ABSTRACT

Recent progress by the North Atlantic Treaty Organisation (NATO) Consultation, Command and Control (C3) Agency (NC3A) Scientific and Technical Support (STS) team has achieved some significant results towards implementing a viable beyond line-of-sight internet protocol (IP) communications capability on board the NATO E-3A airborne warning and control system (AWACS) aircraft. The NATO Airborne Early Warning and Control (NAEW&C) Force Command (FC) sponsored this activity with the purpose of fulfilling mission critical requirements to support current and future NATO mission tasking.

Following introduction and background material, our paper describes potential future missions that drive the pressing capability requirement. We describe next the communications system description with its deployable ground entry point (DGEP), and the IP network architecture for communicating with the NE3A aircraft. We discuss concept development tests and experiments used to verify system functionality and performance, including ground- and flight- testing, and results from the Multi-Sensor Aerospace-Ground Joint Intelligence, Surveillance, and Reconnaissance, (ISR) Interoperability Coalition (MAJIIC) - Technical Interoperability Experiment (TIE) (MAJIIC-TIE). We address a number of issues and challenges we discovered, some with operational impact, including limitations due to bandwidth and latency, Extensible Messaging and Presence Protocol (XMPP) "chattiness", link connectivity loss during refuelling and turns, and issues related to the fact that the aircraft has never before operated with an organic ground element. The next section proposes future enhancements to overcome these issues including, in order of increasing complexity and cost, strategies to optimise low bandwidth utilization and traffic management (such as load splitting over different carriers), and integrating alternative higher bandwidth bearers such as INMARSAT, UHF SATCOM, and broad band SATCOM. While offering significantly enhanced network connectivity, the last of these options, broad band SATCOM, if implemented similarly to the Joint Surveillance Target Attack Radar System (JSTARS), will require significant and costly modifications to the aircraft.

1 INTRODUCTION

Collaborative decision-making is playing an increasing role in the command and control (C2) of deployed forces. Forces engaged in joint operations and deployed over wider areas must rely increasingly on low-bandwidth beyond line-of-sight wireless communication systems and network-enabled capability for their support. This convergence of requirements and constraints – for a networked and collaborative decision-

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support system supported by a low-bandwidth network bearer service – has placed an increased emphasis on the use of chat systems and their operational utility.

The North Atlantic Treaty Organisation (NATO) Airborne Early Warning and Control (NAEW&C) Airborne Warning and Control System (AWACS) aircraft are transforming to support emerging and future roles and missions. There is plenty of incentive to do so. As outlined in SACEUR's 2009 *Concept of Operations for the Employment of the NAEW&C Force* (NAEW&CF), NAEW&CF assets are declared High Readiness Forces and Deployable Forces. [1] Additionally, NATO's MC477 *Military Concept for the NATO Response Force,* identifies NAEW&CF's standing commitment to the NATO Response Force (NRF). [2] In order to support these commitments within the NATO approved transformational framework and its objective NATO Network Enabled Capabilities (NNEC), NAEW&CF assets will be required to participate in Internet Protocol (IP) based networks while airborne. This will become increasingly important as more and more C2 user applications move from stove-piped fixed-format military systems to Commercial Off-the-Shelf (COTS) / Government Off-the-Shelf (GOTS) solutions. NATO's Allied Command Transformation (ACT) and the NATO Consultation, Command and Control Agency (NC3A), have selected IP as the basis for future data convergence and mobile networking. Specifically for the NAEW&CF, NATO articulated the following key "desired outcome" for NNEC:

"<u>Improved Information Accessibility</u> – Ability of Users to access, manipulate and exchange relevant information of different classifications across functional, national and organizational boundaries. This goal is supported by use of a converged, Internet Protocol-based 'protected core' network for voice, data and video traffic on static, deployable and mobile networks."[3]

As the ability to participate in NNEC operations is a specified Long Term Capability Requirement [4] for NAEW&CF, the ability to participate in IP-based deployable and mobile networks will be critical to its future success in supporting its mission commitments.

2 BACKGROUND

The NATO E-3A Component (NE3A), as NATO's only operational unit, has provided the Alliance with airborne surveillance capability since 1982. Initially intended to perform a defensive counter-air surveillance role against Warsaw Pact forces, the NE3A has provided an essential C2 capability over tactical air forces. The NE3A mission evolved to include a tactical air battle management role during Operation ALLIED FORCE over Kosovo, controlling friendly aircraft involved in offensive and defensive counter-air operations, close air support, battlefield air interdiction, combat search and rescue, reconnaissance, tactical air transport, and air–to-air refuelling missions.

Notably, in the aftermath of 9/11, NATO took measures to operationalise Article 5 of the North Atlantic Treaty[1] for the first time in its history. The NE3A deployed to Operation EAGLE ASSIST to support operations in the continental United States. [6] Since then NE3As have supported a broad assortment of contingencies and crises in various capacities, including controlling air defences at NATO Summits, Baltic Air Policing, and other missions.

Due to the nature of emerging missions, in particular the International Security Assistance Force mission in Afghanistan, it became apparent that, unlike in the past, it is operationally necessary for the NE3A to be able to communicate at length directly with ground headquarters (HQ) and operations centres. This implies a pressing need to realise an operationally viable secure air-to-ground beyond line-of-sight (BLOS) airborne 'chat' capability on board the NE3A aircraft.

[1] "The Parties agree that an armed attack against one… shall be considered an attack against them all and consequently they agree … [to] exercise … the right of … collective self-defence …"[5]

Air-to-ground communications capability on board the aircraft presents a challenge. Extant capability consists solely of low-bandwidth waveform carriers, including high frequency (HF) and ultra high frequency (UHF) radios.[2] Interest from the NAEW&C FC in the development of a BLOS chat capability led to a focus on the merits of HF radio and satellite communication (SATCOM) systems, notably IRIDIUM, as the most readily available IP-bearer services. The NC3A Scientific and Technical Support (STS) team has subsequently carried out extensive concept development and experimentation (CD&E) since 2008.

The NC3A STS Team rapidly designed, developed, and tested prototype rack configurations that could be carried in the NE3A to provide the necessary communications capability. They accomplished this within the limitations of the existing communications architecture and without requiring significant and costly aircraft modifications that might require time-consuming airworthiness recertification. In the event, ancillary low bandwidth IRIDIUM SATCOM capability was eventually installed using an antenna that reaches through the aircraft's sextant port.

Within a few months, through innovative design and extensive experimentation with various configurations of hardware and software, the team developed a truly viable chat capability, which was first deployed in support of real world operations in 2009. Coincident with this deployment, NC3A produced five additional prototype racks for use by the NE3A and provided training for logisticians and operators in the configuration, maintenance, and employment of the racks. Progress continued into the fall of 2009 through pioneering ground and flight testing, research and development, and experimentation, and culminated in the Multi-Sensor Aerospace-Ground Joint Intelligence, Surveillance, and Reconnaissance, (ISR) Interoperability Coalition (MAJIIC) - Technical Interoperability Experiment (TIE) and the first ever demonstration of NE3A connectivity to a secure ISR database for query, download, and upload of ISR products from the MAJIIC network.

3 POTENTIAL FUTURE MISSIONS

More recently, increased operations tempo in Afghanistan and counter-piracy operations in the vicinity of the Horn of Africa have motivated NATO to levy additional operational tasks against the NAEW&CF – some of which have extended the platform’s missions to encompass first-responder deployable C2 capability and operational "mission" management, counter-piracy, maritime surveillance and tracking (using the Automatic Identification System (AIS)), air traffic control, support to special operations and time sensitive targeting, as well as monitoring NATO friendly force information (FFI). The ultimate interest is in integration of a collaborative computer information system capability with multi-media support on-board the NE3A platform, and the evolution of the NE3A to become a multi-role, multi-mission platform. The following Figure 1 depicts the evolution of the NAEW&CF roles since 1978.

4 COMMUNICATIONS SYSTEM DESCRIPTION

In addition to the C2 link to the ground, the NE3A communicates air-to-air primarily using Link 11 and Link 16. Its communications systems also include HF, very high frequency (VHF), UHF, and limited SATCOM capabilities for secure and unsecure data and voice. Its air-to-ground data communications capability, however, is somewhat limited, traditionally using uncoded legacy Radio Teletype (RATT) for low-rate (75 bps) serial data exchange. As mentioned earlier, the development of a BLOS capability focused on HF radio and SATCOM systems, notably IRIDIUM, as the IP-bearer services. UHF has also been explored as a LOS adjunct for higher-throughput communications. An on-board local-area-network (LAN) provides flexible and common access to these external bearers by one or more user-end-systems. Figure 2 shows the resultant NATO System View (NSV-1) of the on-board systems. Capability to provide

[2] The NE3A presently has limited organic UHF-SATCOM capabilities.

a secure real-time feed of unclassified maritime AIS track information into the secure network is further afforded using a data diode for accredited low-to-high information exchange.

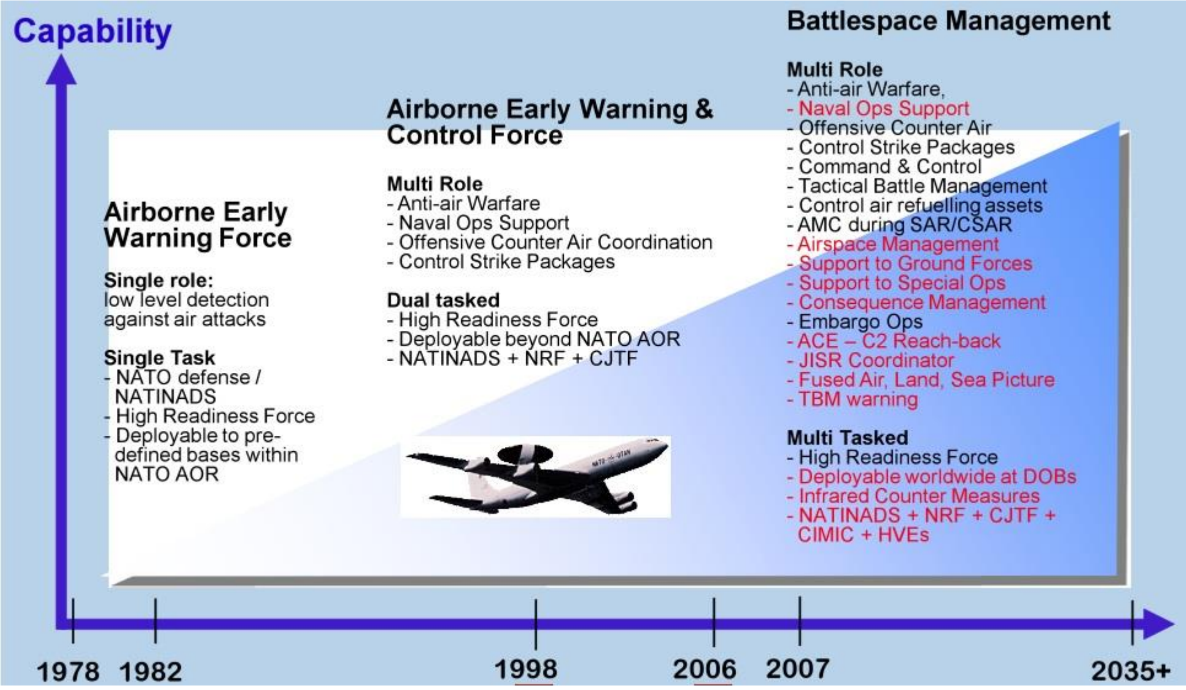

Figure 1: Evolution of the NAEW&CF since 1978. (NAEW&C FC)

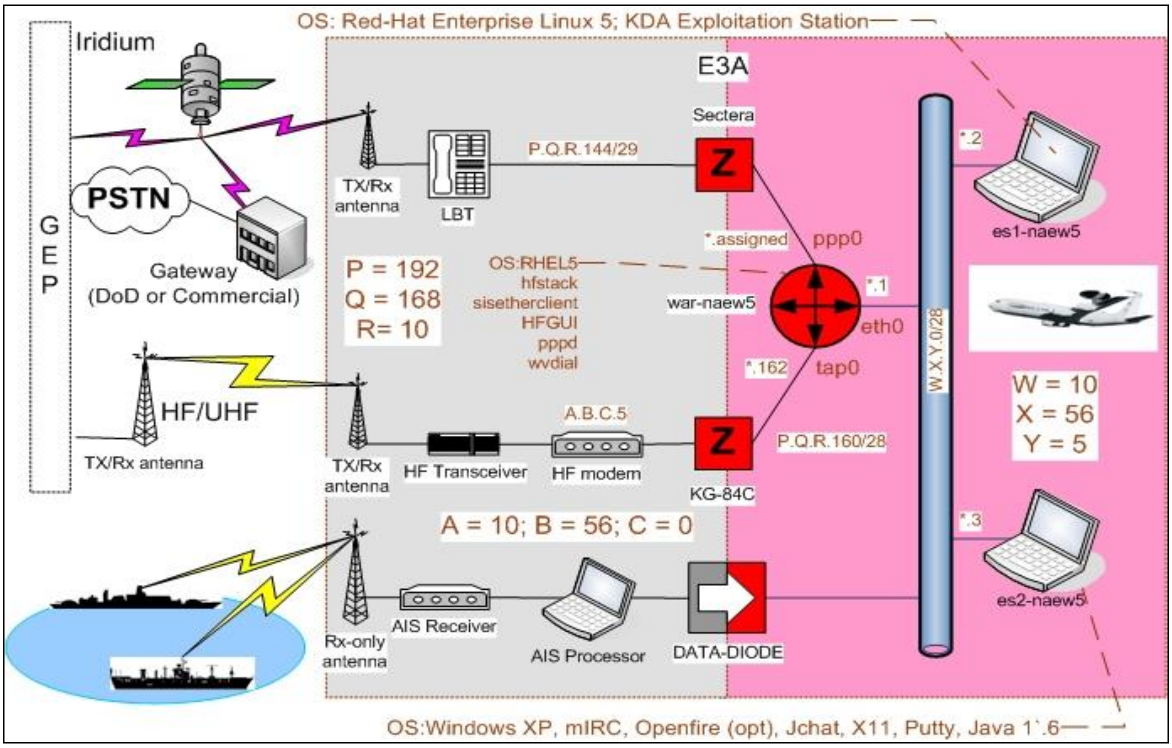

Figure 2: NATO System View (NSV-1) with HF/UHF, IRIDIUM, and AIS connections to NE3A.

High Frequency

Historically, the legacy NE3A possessed some basic E-Mail capabilities via the low bandwidth Data Terminal Airborne (DTA) and its STANAG 5066 [8] HF E-Mail system, available to the NE3A circa 2000. Physical reconfiguration of the aircraft’s mission system during the NATO Mid Term (NMT) upgrade, however, necessitated the removal of this system and an upgraded IP capability was necessary.

Pending development of an IP SATCOM capability as BLOS bearer, the NE3A DTA system was modified, adding a reference implementation of the STANAG 5066 Edition 3 secure IP-over-HF token-ring protocol. [9] This approach allowed re-use of the DTA rack configuration, its Harris 5710A HF modem, and KG-84 encryption unit. Modifications to the airframe were not required, as existing HF radio transceivers, antenna systems, and NMT controls were all used.

IRIDIUM SATCOM

Though the NE3A is equipped with a UHF-SATCOM terminal, its utility for IP-Chat operation has been limited by an on-going NATO transition to DAMA operation, restricted interoperability with on-orbit payloads, and the evolving use of IRIDIUM SATCOM by other E3 platforms. An informal cost-benefit analysis in deploying a usable SATCOM BLOS capability focused on obtaining a usable demand-assigned capability anywhere in the world, and for current NE3A network communication projects this has favoured a focus on IRIDIUM rather than UHF SATCOM. This focus is expected to change in near future however. The NE3A currently uses commercially available IRIDIUM satellite network phones or terminals as its primary means for IP communication, with other media as backup. A General Dynamics Sectera Wireline Terminal with Black Digital Interface provides encryption services for confidentiality. Point-to-point protocol (PPP) operation over the serial digital link provides IP-bearer services.

IRIDIUM Antenna

The AWACS aircraft sextant port (formerly used for navigation) in the aircraft's fuselage just aft of the air-to-air refuelling receptacle greatly aids IRIDIUM integration with the airframe. IRIDIUM antennas can be fitted through the sextant port for exterior communications without need for modification to the aircraft fuselage. Figure 3 shows one such antenna. The antenna extends approximately 8 cm above the skin of the airframe. For flight safety during refueling the antenna is removed from the sextant port and the port is sealed. This forces aircraft disconnect from ground networks and down time when no other media are available.

Figure 3: A Sextant Port IRIDIUM Antenna used in the NE3A (NC3A photo)

Integrated Radio-Router: Media-Access-Control and Router

An integrated radio router (an MPCX-47 general-purpose computer) provides the requisite services to interface the NE3A’s networked applications to the external bearers, including IP-datagram routing services, media-access-control services for HF/UHF radios (implementing STANAG 5066 Edition 3 token-ring protocol) and IRIDIUM (implementing PPP dialup services). Static and dynamic routes amongst the router’s three IP interfaces (*tap0* for HF/UHF, *ppp0* for IRIDIUM, and *eth0* for the on-board LAN) may be configured. Dynamic routing, when used, is tuned with time-outs and update frequencies suitable for the low-bandwidth HF and IRIDIUM links. Addition services are managed by the MPCX-IRR, including time-synchronization with ground-based server. The scope of these services is expanding to include on-board directory-service proxies and route-/gateway- servers, as a means of traffic reduction on the wireless bearers.

Deployable Ground Entry Point (DGEP)

While IRIDIUM offers a conventional telephone service, the added complexity of using this service - with frequent satellite handovers - to support a secure IP connection to a ground station means that some system configuration is necessary in order to get a reliable and resilient IP connection from AWACS to operational HQ. A "plug and play" approach, i.e., attempting to dial directly into an operational HQ's network control centre with IRIDIUM, was reportedly unsatisfactory. [10] The AWACS was often unable to establish and maintain a connection, and as one of many customers, was unable to obtain the priority of service that was necessary. Re-connect times were lengthy, and often disrupted when the IRIDIUM connection failed unexpectedly.

While the NE3A is not a full-fledged ISR platform, most, if not all, airborne ISR platforms have dedicated ground stations to provide tailored wireless connectivity as a prerequisite conduit for their products to their customers. As a focal point for traffic flows and interfaces between ground and air, such stations promote scalable network solutions by localizing unique tuning and configuration requirements for interfaces and servers.

The NE3A, after years of communicating primarily air-to-air, now requires being able to communicate reliably and securely with the ground. Given wide variability in potential operational requirements, range limitations in most wireless IP-bearers, and connection-reliability requirements for applications, NATO has explored development of a DGEP as a prototype for long-term requirements capture. Figure 4 presents the NATO System View of the resultant DGEP design, which provides multi-bearer (HF/UHF/IRIDIUM) capability, local servers as performance enhancing edge-proxies and self-sustainment, RADIUS-secured dial-in and dial-out services, and protected interconnection point(s) with local ground networks.

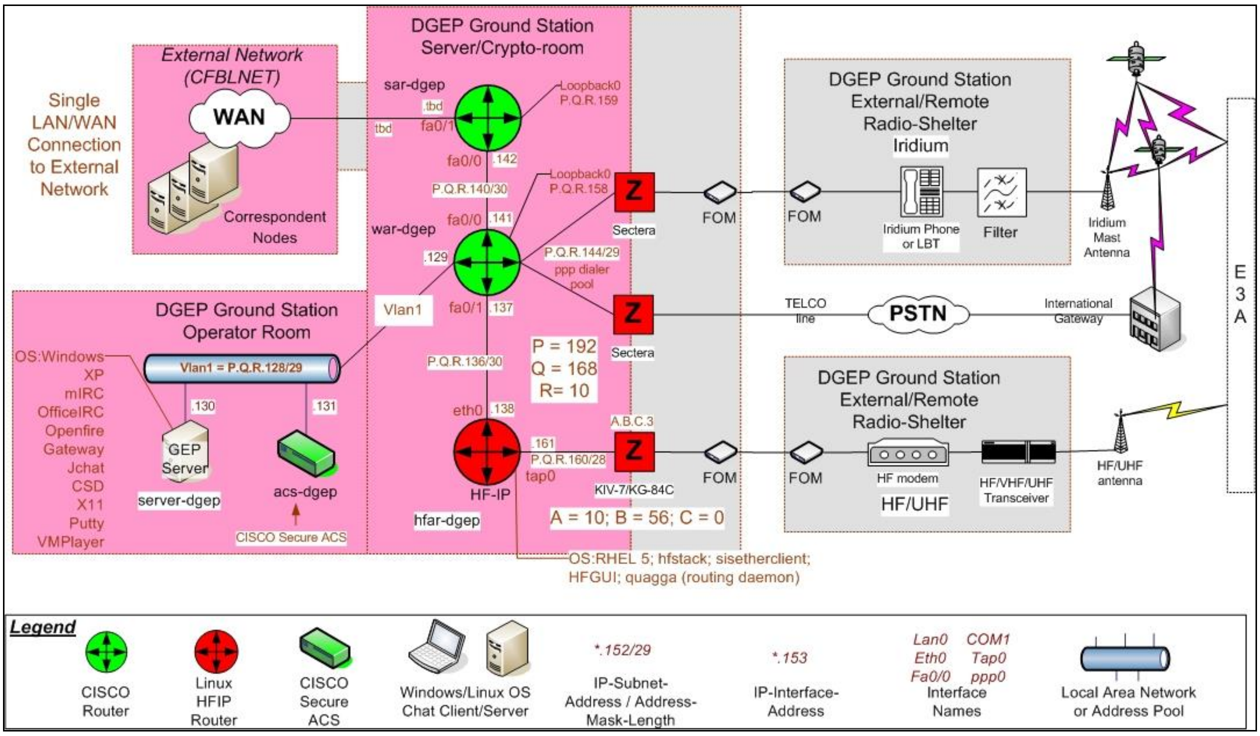

Figure 4: NSV of the Deployable Ground Entry Point depicting HF/UHF and IRIDIUM connections to NE3A (NC3A)

NE3A IP-Chat Capability – NATO System and Technical Views

The NE3A IP-Chat capability combines a number of application, networking and communication protocols into the system-port profiles shown by Figure 5; matching profiles (not shown) are required for end-to-end interoperability and functionality. These profiles encompass a full range of capability and standardization sufficient for NE3A integration into an IP-network architecture.

More significantly, the profiles represent new configuration choices and management responsibility that must be maintained across the NE3A fleet and the ground entry points to which it connects. Management and use of such capability poses new challenges in training for NE3A operators that must be addressed in future for the full utility in use of the capability. As with any new system, performance testing and operational evaluation have shown a wide range of results depending on skill levels and system familiarity of the operators. While disconcerting, this has afforded opportunity for requirements capture in system development.

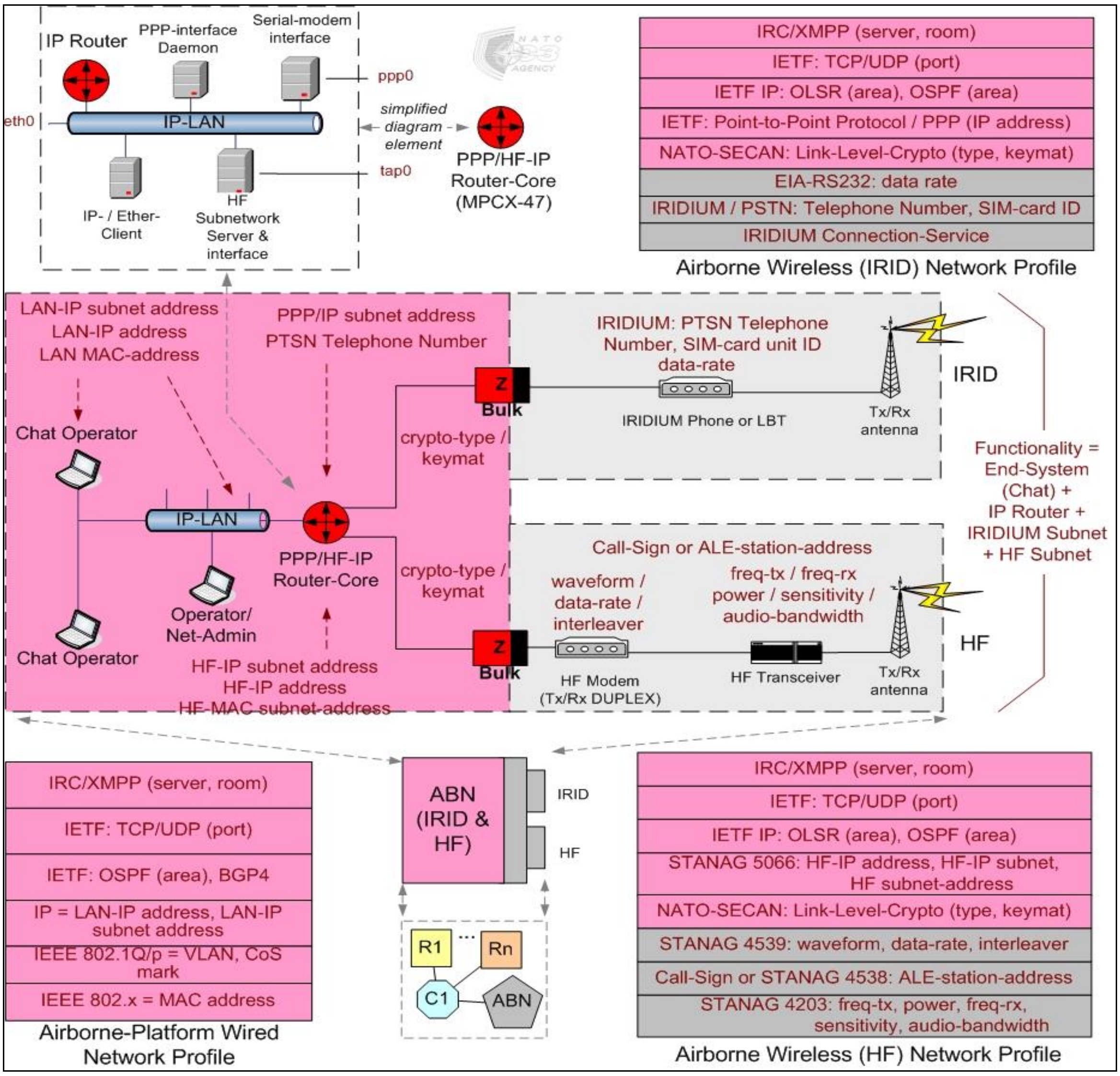

Figure 5: NE3A IP-Chat Capability, System and Technical Views (NC3A)

Chat Protocols

NATO, Allied, and Coalition use of chat systems have focused initially on Internet Relay Chat (most often using the mIRC client implementation). Recent changes in security and interoperability requirements have led to the movement towards long-term use of systems based on the Extensible Messaging and Presence Protocol (XMPP), as used in the NC3A-developed JChat system.

JChat was successfully operated on a UHF Improved Data Modem network with MilStd 188-220 protocol in a lab test at NC3A and in a 2007 flight trial. The XMPP protocol's inherent "chattiness" presented challenges as it consumes significant amounts of available bandwidth – not a desirable trait in a bandwidth-constrained half-duplex radio environment. Significant progress has been made at NC3A to tune JChat in order to reduce the number of transactions and handshakes. Past experiments in preparation for and during MAJIIC-TIE have used a combination of JChat, TRANSVERSE, K-LIVE, and other commercial protocols. Figure 6 depicts the variety of chat protocol clients, servers and gateways. Experiments in the near future will focus on the use of JChat.

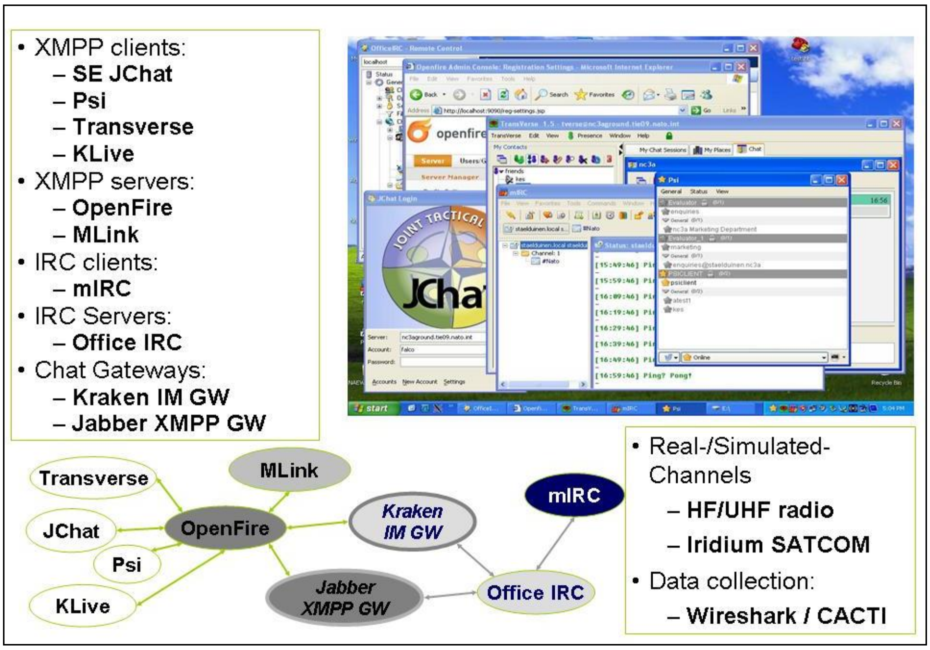

Figure 6: Chat systems: Clients, Servers and Gateways for IRC and XMPP systems (NC3A)

5 CONCEPT DEVELOPMENT AND EXPERIMENTATION (CD&E)

Ground Testing

NC3A uses its remote transceiver site at Staelduinen, NL, established in the late 1950's and extensively renovated in 2005, for ground-to-ground and ground-to-air testing with HF and UHF radio. New site capabilities include flexible remote control of the site's modem-transceiver-antenna connections, enabling configuration for ground-wave, line-of-sight, BLOS long-haul and near-vertical incidence (NVIS) short-haul coverage by switching the site's 500 watt HF radio amongst the available rotatable log-periodic (RLP), inverted-Vee and horizontal-loop antennas. In-laboratory HF network and UHF point-to-point testing is accomplished in NC3A's CAVE laboratory using a wideband high-fidelity audio mixer to replicate the characteristics of air-to-ground and BLOS links, complete with ability to inject noise and jamming signals for circuit realism. NC3A's SATIN laboratory is well-equipped with IRIDIUM

SATCOM systems for dial-in by remote NE3A systems and for local loop-back testing. All these capabilities have proven invaluable in flight-test preparations and in the development of viable system configurations.

Flight Testing

Extensive flight trials have been used to evaluate different system configurations and chat formats, in and about the NE3A operations areas in Europe (as shown in Figure 7) and elsewhere. These have provided excellent opportunity to evaluate pre-mission planning and operator training requirements, as NE3A crew have provided the system operators for most of these flights.

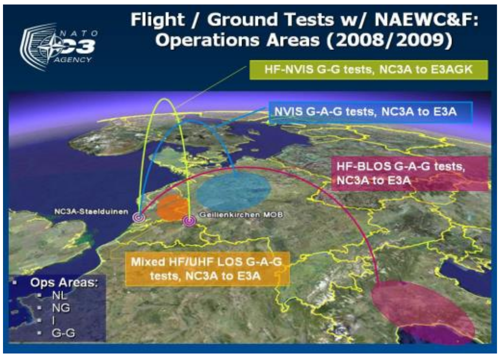

Figure 7: Ground and Flight test operations areas 2008/2009 (NC3A)

MAJIIC-TIE

The MAJIIC project is a multinational[32] effort to maximise the military utility of ISR resources through the development and evaluation of operational and technical means for interoperability of a wide range of ISR assets. The sensor data types addressed in MAJIIC include ground moving target indicator (GMTI) radar, synthetic aperture radar, electro-optical, and infra-red imaging and video sensors, electronic warfare support measures sensors, and artillery locating radar. In order to be adaptable to real-world deployed operations, where the availability of terrestrial and satellite bandwidth might be scarce, MAJIIC supports interoperability using any network type or bandwidth, as well as any combination of networks and interconnections. This approach includes dissemination of near-real time and archived data, the latter by using metadata-based access to and retrieval of archived data from any Coalition Shared Database (CSD) throughout the interconnected MAJIIC environment. These data servers are synchronised to provide full visibility into all archived data throughout the network independent of where the users are located.

During MAJIIC-TIE 2009, a Kongsberg Exploitation System (KES) located on an airborne NE3A was able to access the ground-based network CSD (depicted in Figure 8) and retrieve data and imagery for display, as well as, transfer files to the CSD, while maintaining continuous chat connectivity. Screenshots captured from the aircraft flight are depicted in the Figures 9 and 10.

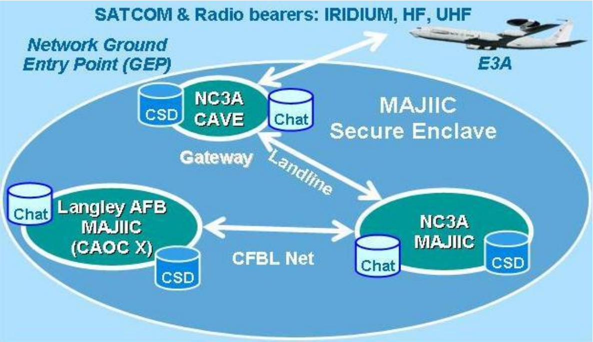

Figure 8: NE3A-MAJIIC-TIE 2009 Environment (NC3A)

[3] MAJIIC Nations include: Canada, France, Germany, Italy, Netherlands, Norway, Spain, United Kingdom and the United States of America. NC3A is the facilitator for the project and provides overall technical management.

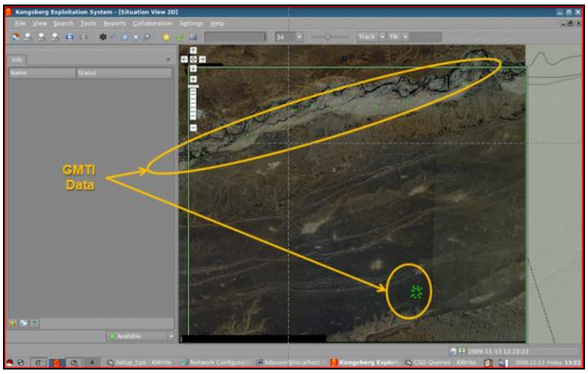

Figure 9: GMTI Data displayed on KES (NC3A)

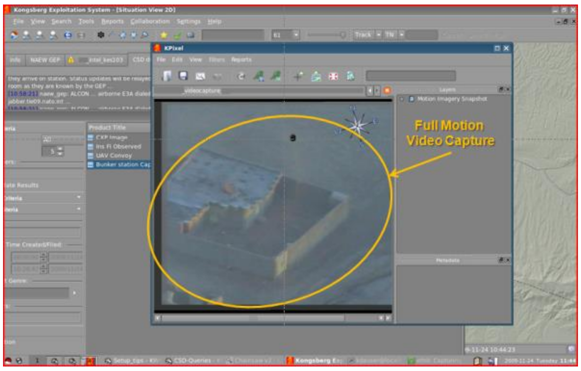

Figure 10: Full Motion Video Screen Capture displayed on KES (NC3A)

FUTURE CD&E

The NE3A and NC3A will continue to conduct experiments through 2010. The principal opportunities are the NATO Coalition Warrior Interoperability Exercise (CWIX) and Empire Challenge.

6 ISSUES AND CHALLENGES

Latency poses technical and operational challenges in low-bandwidth systems. Network protocols and applications are developed on over-provisioned high-speed networks to expect and provide fast response. Client-server applications invoke lengthy and complex dialogs to provide enhanced capability in service-oriented architectures, but offer much higher traffic loads while doing so. With the delay on any link proportional to traffic volume and inversely proportional to link speed, low-bandwidth links are the dominant delay factor, which is compounded by half-duplex channel turnaround in legacy radio systems. The global network introduces additional delays, as aircraft traffic may circle the earth on paths through multiple IRIDIUM satellites and terrestrial gateways back to the ground-based operations centres. Such delays affect operational response and utility, particularly in mixed-network chat environments, as user responses in shared chat rooms may arrive out of sequence or be dropped entirely as lower-level processes (such as TCP-connection management) timeout and reset connections.

Analysis of these issues throughout the system has led to a wide range of mitigation strategies and configuration changes referred to collectively as ‘tuning’. Careful analysis of the XMPP chat-client logon sequence has introduced a set of bandwidth conserving options to the NATO JChat client. Changes in TCP-connection parameters, particularly in initial estimates of the round-trip delay and maximum number of retries, introduce greater system tolerance to round-trip delay. Static pre-configuration of directory and route servers off-loads their traffic from low-bandwidth links, but, as these changes are not broadly scalable in large networks, edge-proxies and XMPP server-to-server federation localize the tuning to the aircraft and DGEP. Further detailed analysis of the traffic flows has detected unwanted contributors (e.g., NETBIOS on end systems) that can be turned off, has established realistic traffic models of chat-room behaviour based on operational experience, and has pointed to unexpected timeout limitations lurking in software libraries that require further exploration and correction.

7 FUTURE ENHANCEMENTS

Future enhancements to the system cover a wide range. Figure 11 below depicts a potential path for future enhancements. In keeping with its initial guidelines for rapid prototyping, the current system is standalone, with its own end-systems to host IP-chat and C2ISR processes. Migration of these processes to the NE3A mission system will require its accreditation to connect to ground-based networks through the DGEP. As an intermediate step, the IP chat capability will be integrated with one or more standalone NE3A situation display consoles (SDC). With new on-orbit capabilities, INMARSAT capability may be added to the NE3A using sextant antennas. Use of bonded IRIDIUM antennae and channels to increase redundancy and bandwidth has been demonstrated in ground tests with the current kit, and awaits installation on the NE3A and flight evaluation. As noted earlier, NAEW&C FC will explore revamping the on board UHF SATCOM system and adding it as a bearer. Advanced IP routing and quality-of-service management regimes for multi-bearer operation are currently being evaluated and will be included in later versions of the prototype.

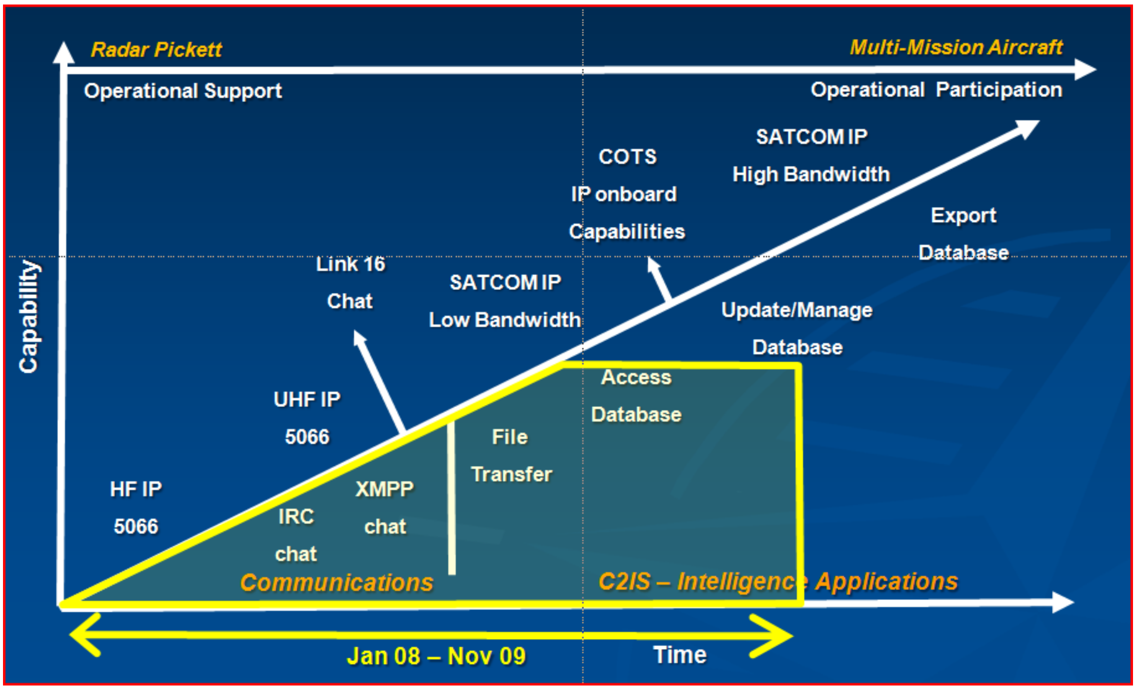

Figure 11: Depiction of Future Enhancements to NE3A (NC3A)

Ultimately, installation of stable high-speed air-to-ground communications system at Ku-band (e.g., TCDL or Ku-Band SATCOM) would provide ample bandwidth (> 10 Mbps) to meet new mission requirements; but these will require extensive analysis, airframe rework, and airworthiness recertification before they could bear fruit. Pending such development, the multi-bearer approach explored and described herein will be capable of meeting the initial goals for new C2ISR missions. The most significant future enhancements must also focus on training, logistics, and system management for improved operational performance.

8 CONCLUSIONS

NATO now possesses a viable beyond line-of-sight IP communications capability on board the NE3A AWACS aircraft. This first step into the NNEC community provides the basis for future transformation of the platform, specifically from pure air/surface surveillance and air battle management to that of a multi-mission aircraft supporting the full range of NATO C2ISR requirements for joint commanders at all levels (operational to tactical) and across all components.

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